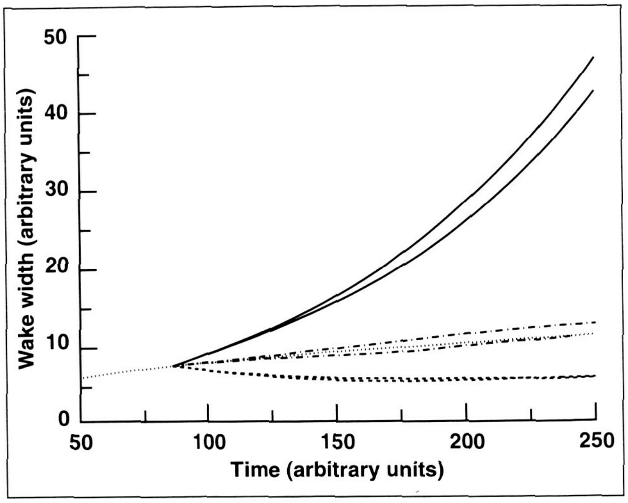

Fig. 1. The evolution of wake widths for a turbulent wake subjected to various plane strains. Solid lines denote flows stretched in the cross-stream direction; dashed lines, flows compressed in the cross-stream direction; and chain-dotted lines, flows with no strain in the cross-stream direction. The dotted line is the result from the unstrained wake simulation.

associated with the wake is found to decay and the flow evolves toward a pure straining flow.

The combination of turbulence production through both strain and time-varying wake shear provides a difficult test case for turbulence models. All terms in the Reynolds stress balance have been computed at several times for each of the simulations and are being compared with predictions of various turbulence models. The detailed information available in the simulations will provide guidance on how to improve the existing models so that they will better predict the turbulent flow over a high-lift airfoil.

Point of Contact: M. Rogers
(650) 604-4732
mrogers@nas.nasa.gov

A Model for the Limiting Piston Stroke in Vortex Ring Formation

K. Shariff

Many devices eject a mass of fluid either in one shot or periodically. Examples include heart valves and flapping wings. Often the goal is to maximize the volume of fluid moving as a coherent vortex ring away from the exit. M. Gharib (California Institute of Technology) used a piston to experimentally study fluid ejected from a pipe and found that the largest coherent mass of fluid was attained at a piston stroke (normalized by diameter) of 4 under a variety of circumstances, including different histories of the piston motion. For longer strokes, the mass broke up into smaller vortices and a trailing jet. He also found that this maximum stroke, when expressed as a time, corresponds to the ejection period of many biological systems, including normal hearts.

The present contribution was a simple model that predicts the limiting stroke and the associated properties of the vortex such as circulation. Reasons for insensitivity to piston motion emerge from the model, and piston motions that maximize the ejected mass were obtained.

The model is based on Lord Kelvin's (1880) result that among all vortex motions with given impulse and circulation, the steady one has maximum energy. In the present situation, one finds that after a certain critical piston stroke, one cannot keep feeding enough energy (in comparison with impulse and circulation) to maintain this maximum and so the vortex becomes unsteady. This critical value agrees with the experiments, is quite insensitive to different piston histories, and correctly predicts the slight dependencies observed experimentally. Subsequently, numerical simulations by M. Rosenfeld

(Tel-Aviv University) found a strong sensitivity of the limiting stroke to the exit velocity profile and a lack of sensitivity of ring circulation to both the exit profile and piston motion. The model reproduces these facts as well. Finally, using an inverse design procedure, piston histories were found that may overcome the limit at a stroke-to-diameter ratio of 4 and thereby lead to larger coherent masses.

Point of Contact: K. Shariff
(650) 604-5361
shariff@nas.nasa.gov

B-Spline Method for Turbulent Flow Simulation

A. Kravchenko, P. Moin, K. Shariff

B-splines are an attractive basis for a numerical method. Because of the continuity of a high number of derivatives, B-splines have resolving power approaching that of spectral functions, but provide greater flexibility in geometry and grid distribution. They are not as flexible as finite elements, but they are much more accurate for the same number of degrees of freedom. Furthermore, if they are used in a Galerkin formulation, the resulting scheme conserves not only the discretized quantities (such as mass and momentum) but quadratic invariants as well (such as kinetic energy for inviscid incompressible flow). This protects the scheme against aliasing and ensures that there is no numerical smoothing of the unresolved scales of motion.

The B-spline method was implemented for incompressible flow in two generalized coordinates using a Galerkin formulation. Fourier expansions are used for the third direction. The B-spline zonal mesh capability developed by Shariff and Moser (1995), which gives the same high degree of derivative continuity at zonal boundaries as everywhere else, is used. It increases gridding flexibility and leads to a significant reduction in the number of grid points required. Basis vectors are used that already satisfy the incompressibility constraint. This leads to a reduction in the number of degrees of freedom from four to two per grid point. However, there is a high cost associated with calculating the Galerkin nonlinear term and in inverting the mass matrix. More work is required to improve the efficiency of the method.

In the figure, the experimental (symbols) and computed (lines) frequency spectra in the wake of a turbulent flow past a circular cylinder at a Reynolds number of 3900 are compared. The computations are all large-eddy simulations with the dynamic model. The curves show the result of three different numerical methods. The B-spline method (solid line) with quadratic basis functions gives excellent accuracy up to the smallest scale it resolves (shown by the chain-dotted vertical line). The energy-conserving second-order finite-difference scheme (dashed) is accurate for a smaller range of frequencies, whereas the fifth-order upwind biased scheme (chain-dashed) is much too dissipative for a large range of scales.

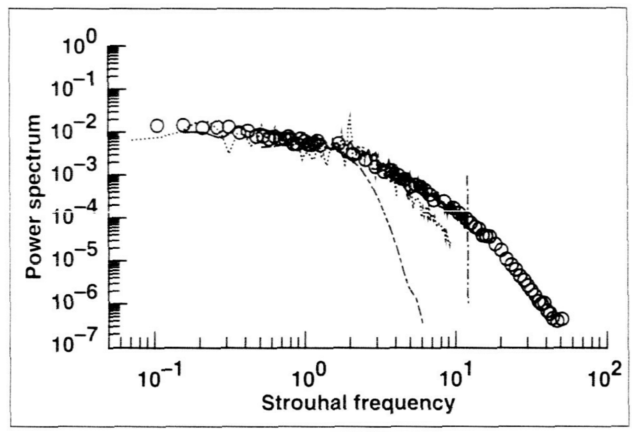

Fig. 1. Frequency spectrum of velocity fluctuations in the wake of a circular cylinder showing the resolving power of various schemes.

Point of Contact: K. Shariff
(650) 604-5361
shariff@nas.nasa.gov